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SUPERCONDUCTIVITY: CHALLENGES AND PROSPECTS OF APPLICATION

Abstract: Superconducting materials almost completely lose their electrical resistance when cooled below a certain critical transition temperature. The phenomenon of superconductivity can truly revolutionize modern science. However, scientists have not yet discovered materials with high critical temperatures. Nevertheless, there are many commercial applications of superconductors in different spheres of industry.
Key words: superconductivity, superconductor.

A superconductor is an element or metallic alloy which, when cooled below a certain critical temperature T_c, dramatically loses all electrical resistance. In principle, superconductors can allow electrical current to flow without any energy loss. Superconductors are characterized by the Meissner effect, the complete ejection of magnetic field lines from the interior of the superconductor as it transitions into the superconducting state.

Superconductivity was discovered in 1911 when mercury was cooled to ≈4°K by Dutch physicist Heike Kamerlingh Onnes [2]. The first microscopic theory of superconductivity was proposed by scientists Bardeen, Cooper and Schrieffer (BCS theory) [5].

Such discoveries initiated a race to find materials that function as superconductors at much higher temperatures.

The phenomenon of superconductivity can truly revolutionize modern science and electric power infrastructure. Using superconducting materials, today's scientific research facilities are pushing the frontiers of human knowledge and pursuing breakthroughs that could lead to new techniques ranging from the clean energy from nuclear fusion to computing at speeds much faster than the theoretical limit of silicon technology.

Despite all the advantages of superconductors, scientists have to keep in mind the challenges that they have to face to properly implement any superconductive technology in real life [7]:

- Refrigeration
- Cost
- Reliability
- Acceptance

As the cost of the superconductor is always much higher than the cost of a conventional conductor, superconductor must bring overwhelming effectiveness to the system. The discoveries of HTS have changed the dynamic of refrigeration by permitting smaller and more efficient cooling systems. However, design, integration of superconducting technologies, demonstration of systems benefits and long term reliability must be met before superconductivity can be implemented into new applications.

Superconductor-based products are extremely environmentally friendly compared to their conventional counterparts. They generate no greenhouse gases and are cooled by non-flammable liquid nitrogen (nitrogen comprises 80% of our atmosphere) as opposed to conventional oil coolants that are both flammable and toxic. They are also typically at least 50% smaller and lighter than equivalent conventional units which translate into economic incentives.

Current Commercial Applications [3]:

- Magnetic Resonance Imaging (MRI)
- Nuclear Magnetic Resonance (NMR)
- High-energy physics accelerators
- Plasma fusion reactors
- Industrial magnetic separation of kaolin clay

Emerging applications [4]:

- Electric Power. The high power density and electrical efficiency of superconductor wire results in highly compact, powerful devices and systems that are more reliable, efficient, and environmentally benign.
- Transportation. Superconductors are enabling a new generation of transport technologies including ship propulsion systems, magnetically levitated trains, and railway traction transformers.

- Medicine. Advances in HTS promise more compact and less costly Magnetic Resonance Imaging (MRI) systems with superior imaging capabilities. In addition, Magneto-Encephalography (MEG), Magnetic Source Imaging (MSI) and MagnetoCardiology (MCG) enable non-invasive diagnosis of brain and heart functionality.
- Communications. Over the past decade, HTS filters have come into widespread use in cellular communications systems. They enhance signal-to-noise ratios, enabling reliable service with fewer, more widely-spaced cell towers. As the world moves from analog to all digital communications, LTS chips offer dramatic performance improvements in many commercial and military applications.

Back in April 2014, the CERN Superconductors team announced a world-record current in an electrical transmission line using cables made of the MgB_2 superconductor [1]. This result proved that the technology could be used in the form of wire and could be a viable solution for both electrical transmission for accelerator technology and long-distance power transportation.

Now, the MgB_2 superconductor has found another application: it is to be tested in a prototype coil that could provide the solution to ensure safe trips for astronauts during deep-space missions. The idea is to create an active magnetic field to shield the spacecraft from high-energy cosmic particles. During long-duration trips in space and in the absence of the magnetosphere that protects people living on Earth, astronauts are bombarded with high-energy cosmic rays that might cause a significant increase in the probability of various types of cancers. Because of this, exploration missions to Mars or other distant destinations will only become realistically possible if an effective solution for adequately shielding astronauts is found [6].

Conventional superconductor theory says that a very light metal should have a high transition temperature. The best would be the lightest element, hydrogen, but it is hard to turn it into a metallic state. Hydrogen-dominated materials can be transformed to metals with much lower pressure than pure hydrogen. So, scientists used H_2S and worked with a tiny anvil made of two gem-quality diamonds, the tips of which were jammed together to about 100 gigapascals.

However, it is still not completely clear to scientists what is happening in the heart of that diamond anvil. It seems like the H_2S might actually be turning into H_3S under all that pressure, and that might be the real superconductor.

Under all that pressure hydrogen sulfide goes superconducting at 203 K, the temperature that exists in Antarctica.

Back in 2015 Lexus released a prototype of a hoverboard. However, the company has not released any specific information about how it works.

To levitate the superconductor, all you need to do is embed the superconductor in the magnetic field a couple of inches above some kind of magnetic surface. If you tried to move the superconductor, you would kickstart circular eddies of electrical current on the superconductor's surface, spawning miniature magnetic fields that work to the superconductor in place. These eddy currents even oppose gravity, pushing off of the surface's magnetic field to keep the superconductor floating in midair. The lack of electrical resistance in superconductors means that once an eddy current starts, nothing can sap its strength. As long as you keep the superconductor cold, it will stay floating above a magnet, its eddy currents fighting gravity to a draw.

If the superconductors are located inside the hoverboard, then we need an outside magnetic field for the hoverboard to coast on, because levitation happens when the superconductor interacts with *an outside magnetic field*. So, it appears that Lexus laid down a bunch of very strong rare-earth magnets underneath the "sidewalk," setting up a magnetic field powerful enough to support both board and a rider.

The superconductive state enables a range of innovative technology applications that can truly revolutionize our world. And many challenges would be solved if more research in this sphere were conducted and scientists discovered superconductive materials with room critical temperature or discovered practical ways of reaching superconductive state of such materials.

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СВЕРХПРОВОДИМОСТЬ: ПРОБЛЕМЫ И ПЕРСПЕКТИВЫ ПРИМЕНЕНИЯ

Аннотация: сверхпроводимость — свойство некоторых материалов обладать нулевым электрическим сопротивлением при достижении ими температуры ниже критической. Освоение этого явления может по-настоящему совершить прорыв в науке. Но до сих пор учёными не были найдены материалы с критической температурой, близкой к комнатной. Несмотря на это, явление сверхпроводимости активно используется в различных сферах нашей жизни.

Ключевые слова: сверхпроводимость, сверхпроводник.

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